10CFR835 ALARA Design Document for C-AD

Background

From 10CFR835 § 835.1002, Facility Design and Modifications:

During the design of new facilities or modification of existing facilities, the following objectives shall be adopted:

(a) Optimization methods shall be used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls.

(b) The design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupational occupancy (2000 hours per year) shall be to maintain exposure levels below an average of 0.5 mrem (5 microsieverts) per hour and as far below this average as is reasonably achievable. The design objectives for exposure rates for potential exposure to a radiological worker where occupancy differs

from the above shall be ALARA and shall not exceed 20 percent of the applicable standards in § 835.202.

(c) Regarding the control of airborne radioactive material, the design objective shall be, under normal conditions, to avoid releases to the workplace atmosphere and in any situation, to control the inhalation of such material by workers to levels that are ALARA; confinement and ventilation shall normally be used.

(d) The design or modification of a facility and the selection of materials shall include features that facilitate operations, maintenance, decontamination and decommissioning.

With regard to 10CFR835 § 835.1002 (a), optimization methods are prescribed in C-A OPM 9.5.6, ALARA Optimization and Cost Benefit. The purpose of that procedure is to compare dose savings over the life of a system to the cost of the design, installation and maintenance. Cost-benefit analysis is a technique that helps optimize a given radiation protection practice or it is used to select between proposed practices. The C-AD liaison engineer and liaison physicist, with the help of C-A Department ALARA Committee members, perform the analysis. The ALARA Committee Chair may elect to perform a qualitative analysis or a quantitative analysis.

The following considerations are addressed for a qualitative approach to the analysis:

- Identification of the system or component
- Recognition of the affected groups and their needs
- Selection of the alternatives to be evaluated
- Decision to select from the available alternatives

As an option, an analysis may be used for a quantitative cost-benefit determination. If selected as the optimization method, then a calculation of collective dose for the operation over the time under consideration must be made. The dose may be based on archival reports, operation and maintenance histories, survey results, occupancy and other relevant data. The computation of collective dose is as follows:

(Person-rem/job) (Jobs/year) (Years) = Collective Dose

One must calculate the collective dose for the same period considering the alternative that employs a dose-reduction option. The alternative also may be justified if it can enhance system safety or reliability. If a reasonable alternative does not exist, a quantitative cost-benefit analysis is not warranted.

For quantitative analysis, one evaluates the cost of each alternative in terms of:

- Manpower requirements
- Design and engineering cost
- Operating and maintenance cost
- Retirement and disposal cost
- Radiation exposure to implement the alternative, to maintain and operate the system or component and to dispose of equipment and facilities

For purposes of quantitative cost-benefit analysis, a value of $11,000 per person-rem is used by the C-A Department. For each alternative, one obtains the product of collective dose and $11,000/person-rem. The monetary value of $11,0000 per person-rem is based on a monetary value used by nuclear power plants in the United States to assist in management decisions regarding dose reduction plant modifications or equipment investments.[1] One compares this monetary value with the cost of the alternative. After all costs are determined, political, social and programmatic factors are considered. Based on cost-benefit analysis and the other factors, one selects the appropriate alternative.

With regard to 10CFR835 § 835.1002 (b), the design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupancy, 2000 hours per year, is to maintain exposure levels below an average of 0.5 mrem per hour and as far below this average as is reasonably achievable. The design objective for exposure rates where occupancy is not continuous is ALARA and does not exceed 1 rem per year. See C-A OPM 9.1.12 Procedure for Review of C-A Shielding Design.

With regard to 10CFR835 § 835.1002 (c), the design objective for C-AD for the control of airborne radioactive material is to avoid releases to the workplace atmosphere and to control the inhalation of such material by workers to levels that are ALARA; and to use confinement and ventilation. See C-A OPM, 9.5.2 ALARA Design Review.

[1] North American ALARA Center, College of Engineering, University of Illinois, http://hps.ne.uiuc.edu/isoedata/html/Dollars_per_Person_REM_Saved.htm

With regard to 10CFR835 § 835.1002 (d), the design of C-AD and the selection of materials include features that facilitate operations, maintenance, decontamination and decommissioning. See C-A 9.5.4.e, Summary of C-A ALARA Practices.

From Section IV, Subsection H, DOE G 441.1-2, “Occupational ALARA Program Guide for use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection:”

The level of effort involved in documenting ALARA decisions should be commensurate with the potential dose savings to be realized. A detailed evaluation need not be made if its cost, including the cost of documentation, outweighs the potential value of the benefits. The procedure used to evaluate the "appropriateness" of dose-reduction and contamination minimization decisions should be maintained. The RCS and PNL-6577 provide additional guidance on optimization methodologies.

From Section IV, Subsection I:

The ALARA design review should have six discrete phases:

1. Dose assessment.
2. Review of radiological conditions against the trigger levels established by management, e.g., creation of a new radiation source or an increase in the dose rates from an existing source; increased operations, maintenance, production, research,

inspection or decommissioning requirements in a radiological control area; projected expenditure of a collective dose of greater than 1,000 mrem.

3. Identification of the applicable radiological design criteria.
4. Review of previous similar jobs, designs and processes that have similar hazards to assist in the selection of design alternatives and selection of optimum alternatives using approved optimization methods for evaluating the various ALARA considerations.
5. Incorporation and documentation in the design package of features to reduce dose and the spread of radioactive materials.
6. Post-construction reviews of effectiveness of engineering features to reduce dose and the spread of radioactive materials to provide feedback to the design engineers and help refine the design process.

The procedure describing the process of ALARA design review, including the results of dose assessments, the review of ALARA criteria, the optimization/cost-benefit analysis records, and the recommendations on features to reduce dose and radioactive contamination has been approved by management of the Collider-Accelerator Department and BNL. See C-A OPM, Chapter 9 and SBMS Subject Area, Accelerator Safety.

An example ALARA design review record is part of this document and is included o show that such records are readily retrievable. Radiological design considerations are discussed in C-A OPM 9.5.2, ALARA Design Review and SBMS, Design Practice for Known Beam Loss Locations.

Example ALARA Design Review Record for NSRL Facility Illustrating Six Discrete Phases of ALARA Design Review

Dose Assessments

Maximum annual dose to a C-AD User (experimenter) occupying the NSRL Support Laboratory 1500 hours per year is 10 mrem. The maximum dose point is the mouth of the labyrinth leading to the Target Hall.[2] Occupancy is expected to average about 4 to 5 people for 1500 hours per year. The maximum estimated collective-dose to Users in the Support Labs is about 50 person-mrem per year.

The estimated doses[2] from skyshine at the closest occupied non-C-AD facilities are:

- 0.27 mrem per year at Building 919, which is a C-AD beam-line component assembly-area, and occupancy is 2000 hours per year by 3 to 4 people.
- 0.0013 mrem per year at Building 931A (BLIP), and occupancy is part time by 1 to 3 people.

The collective-dose from C-AD operation is negligible.

Dose from airborne radioactive emissions at site boundary is 0.00001 mrem per year.[3] The collective-dose is negligible.

[2] NSRL SAD Appendix 1. Dose point is entrance to labyrinth leading to Target Hall.
[3] NSRL SAD Appendix 4.

Dose to Users in the Target Hall from beam-stop gamma-shine is taken as the product of four factors:

1) The steady-state dose rate at 1 meter from short-lived activation, 16 mrem/h.[4]
2) 22.5% single-person occupancy, which is the percentage operation time assumed to be needed to place targets at the target station.
3) 1500 hours of operation per year.
4) A factor to correct for distance.

The percentage occupancy was based on one person for 30 seconds every 5 minutes to change samples and two persons for 15 minutes every 4 hours to set up a new set of experiments. The distance from the re-entrant cavity to the target station is about 3 m. Assuming a volumetric cylindrical source of activation products and assuming Users stand 2 m from the face of the re-entrant cavity leading to the beam stop, then the unshielded collective-dose estimate is about 650 person-mrem per year, or a cost of $7,200 per year. A 2-inch thick iron shield at the face of the re-entrant cavity would reduce this collective dose estimate by about a factor of four to 170 person-mrem per year.

Review of Radiological Conditions versus Trigger Levels

There are no ALARA trigger levels for instantaneous or short-term incremental quantities for dose-equivalent rate in units of mrem/h or mrem-in-one-hour, respectively since exposure at C-A facilities is not due to continuous level sources of radiation. Instead, C-

[4] NSRL SAD Appendix 7.

A Department ALARA design triggers are in terms of collective dose to persons, which is impacted by factors such as distance from the source and occupancy time.

In addition, there are radiological triggers that are related to ALARA design review but are not in themselves related to the level of radiation protection. For example, triggers used solely to gain public acceptance dominate the ALARA design review for activated soil, but the costs for capping activated soil to prevent rainwater infiltration are not part of a cost-benefit analyses for radiological protection. That is, a water repellant cap along the entire length of the C-AD tunnel is required based on a trigger of potentially exceeding 5% of the Drinking Water Standard in groundwater regardless of the cost of capping. The cap will likely prevent any contamination of the aquifer. However, no radiological dose to people is expected if a cap is not installed and contamination occurs. This is because drinking water supply wells are too distant from the source.

The Collider-Accelerator Department has the following four collective-dose levels that trigger a formal ALARA design review by the C-A ALARA Committee:[5]

- Installation of a new accelerator system, experiment or beam-line component expected to result in > 750 person-mrem collective exposure.
- Operation of a beam-line component, experiment or accelerator system during its lifetime expected to result in > 750 person-mrem/year averaged over a two-year period.

[5] C-AD OPM 9.5.2, ALARA Design Review.

- Future routine maintenance of a new beam-line component, experiment or accelerator system expected to result in > 0.75 person-rem/year averaged over a two-year period.
- Replacement, removal or rebuilding an existing beam-line component or accelerator system expected to result in > 0.75 person-rem/upgrade.

Collective-dose to Users in the Support Laboratories and the Target Hall, collective-dose to occupants at nearby facilities, and collective-dose to persons at the site boundary do not meet any of these triggers. While not meeting a trigger, the potential dose to Users in the Target Hall from beam-stop gamma-shine was judged to require further study, hence Appendix 7 of the NSRL SAD was developed and the following statements further document a specific cost-benefit analysis for shielding out the gamma-shine from the beam stop.

In the ALARA design review process at C-A Department, the need for further study is generally obvious and the focus is normally on possible design options that have different implications for protection, cost and other factors. The performances of the options are usually predicted together with the operational implications. We note, for example, the number of legs to the labyrinth was optimal; that is, more legs or fewer legs produced higher dose estimates. With regard to the Target Room roof shield, the thickness of concrete was based on soil activation considerations. However, the combined concrete and soil layers of the Target Room roof were based on several factors including steepness of the berm and sky-shine dose estimates. With regard to beam path in air in the Target Room, programmatic needs were considered in optimizing the length of the vacuum pipe.

In the case of exposure of Users to residual radiation from the C-AD beam stop, cost, protection and other factors were considered and details are given here.

A specific ALARA investment is a 2-inch plate of iron or equivalent material that moves into place when a person enters the Target Room in order to shield out the gamma radiation from the activated beam stop. It is estimated to take 30 seconds to move such a shield into place. Based on one entry every 5 minutes to change a sample, approximately 20% more time (one minute every 5 minutes) is needed to move the shield into and out of the beam path before each experimental irradiation. Some of this time will overlap with the time it takes to enter and exit the target room if the shield's motion begins as a person enters or leaves. Integrated over a 1500-hour running period, the shield may idle the program significantly each year because of the delay involved in moving the shield. The cost of additional electric power to keep the beam line idle and ready for beam is significant. Approximately 0.5 MW are needed to maintain that portion of the beam line that would remain on during accesses to change samples in the Target Room. At this time (FY2001), the cost per MW-hr is $60. For a 7% increase in idle time, one hundred hours per year, the cost is $3000. A 7% increase is used as opposed to the full 20% increase since some time overlaps with User access and egress. In addition to this cost, the cost of the movable shield itself is approximately $7,000. This includes the cost of labor for fabrication and installation ($2000), materials ($3000), and security hook-up ($2000). It is noted that interlocks are needed to ensure the shield is out of the beam path during irradiations.

Additional factors such as impact on experiments and reduced area allotted for experiments are also considered. For example, frequent rapid entry may be needed for certain types of experiments or experimental runs. In this case, the shield would not be used. Quick entry, simple target mounting and quick exiting procedures would be the focus of ALARA efforts. On the other hand, for some experiments, significant set-up time may be called for and a beam-stop shield would be beneficial. Finally, the area allotted for experiments is limited due the fixed size of the Target Room. The shield and mechanism to move the shield may need to be removed in order to accommodate a future experiment.

Based on the above, a cost-benefit analysis does not suggest a movable shield for the Booster beam stop is warranted. Total cost is about \$10,000 and total benefit is about \$5400 since dose from the gamma-shine is reduced, not eliminated. However, other factors, which are desire to minimize User exposures and cultivation of good will, dominate the eventual decision, even though these factors are not part of the cost-benefit analysis. Thus, a movable shield will be installed and it will be used whenever practicable.

The use of a person-rem period of one year is reasonable in this case. One can choose between short-term cost-benefit analysis and long-term cost-benefit analysis. In this case, power costs were annualized and future dose received by Users was not discounted to account for dose received during shield repairs or removal. The future costs of decommissioning were not included nor were the costs of future annual interlock testing and repair. These types of costs are pertinent to long-term cost-benefit analysis. On the detriment side of the equation, there was an assumption in the dose calculation of 30 days of continuous irradiation with full beam on the dump. It was also assumed that Users worked only on the downstream side of the target, which pushed the short-term dose estimate upward. One could include future years' dose to Users and do a long-term cost benefit analysis, but one should consider the actual up and down running period that is likely to occur, and the actual positions of users. One would need to account for buildup and decay at night, on weekends and during downtimes. In addition, one needs compare this future detriment against all the long-term costs of the shield. The short-term approach was done in the spirit of DOE G 441.1-2, whereby the level of effort involved in documenting ALARA decisions should be commensurate with the potential dose savings to be realized.

Identification Of The Applicable Radiological Design Criteria

From the SBMS Subject Area for Accelerator Safety, the applicable BNL design criteria, which have been met, are:

- Less than 25 mrem in one year to individuals in other BNL Departments or Divisions adjacent to the C-AD.
- Less than 5 mrem in one year to a person located at the site boundary.
- Offsite drinking water concentration and on-site potable well water concentration less than 4 mrem to an individual in one year from C-AD operations.

- Less than 1000 mrem in one year to a Collider-Accelerator Department staff member or User from operation and maintenance of C-AD.
- Less than 10,000 pCi/L tritium concentration of in the BNL sanitary sewer effluent caused by liquid discharges from C-AD averaged over a 30-day interval.
- Groundwater contamination from C-AD soil activation is to be prevented.
- Less than 0.1 mrem in one year to a person at the site boundary from C-AD airborne effluents.

It is noted that the C-A Department planned the C-AD shielding with ALARA in mind, which is that during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control.[6] Assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b). Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face doses are often acceptable, but well within the ALARA design objective.

[6] See the NSRL SAD Chapter 4, Section 4.6.1.1.

Review Of Previous Similar Jobs, Designs And Processes That Have Similar Hazards

Based on actual monthly doses for the 1999 and 2000 operating cycles for RHIC and NASA programs, approximately 250 person-mrem are accumulated per month of collider-accelerator operation and 1500 person-mrem per month of collider-accelerator maintenance.[7] Collider-accelerator operations were performed with high-energy heavy-ions similar to the proposed NASA program at C-AD; however, dose from maintenance reflects high intensity proton operations as well. These values of collective dose are for Collider-Accelerator staff and Users who are radiation workers. Given that heavy ions from C-AD program represent less than 0.01% of the total nucleons accelerated in the Booster in any given year, it is unlikely that C-AD will affect C-A Department collective dose to any significant extent.

Collective-dose from operations and maintenance of the TVDG, Linac, Booster and AGS accelerators were factored into the monthly collective-dose estimates. It is noted that only the TVDG or Linac and the Booster are required for C-AD heavy ion or proton operations. Overall, radiation exposure reduction is managed effectively at the complex; see the following figures. It is noted that physics programs, the number of radiation workers and the beam intensity have been increasing over the last four decades while the collective dose has been steadily decreasing (see Figure 1).

[7] BNL Memorandum, C. Schaefer to D. Lowenstein, C-A FY 2001 Collective Dose Goal, October 12, 2000.

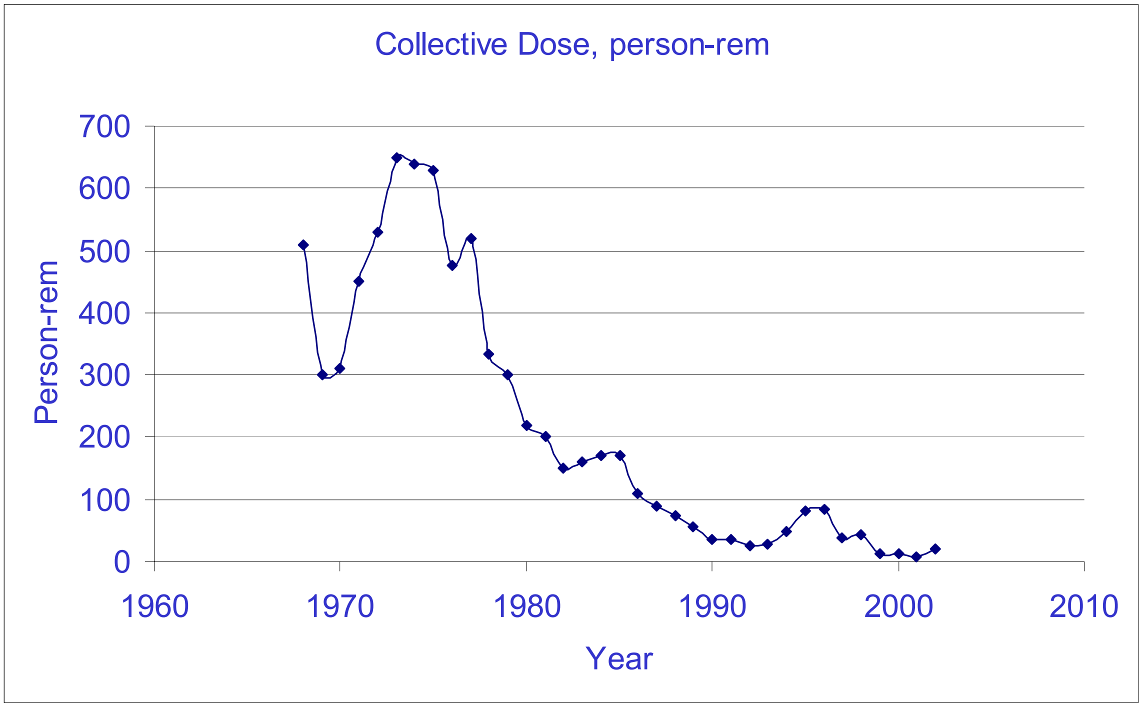

Figure 1, C-A Department Archival Collective-Dose Record

The greatest amount of dose-reduction has come by way of Accelerator Improvement Projects. Funds from these projects were used by the C-A Department to improve the reliability of vacuum systems, beam injection systems and beam extraction systems. Additionally, the Experimental Support and Facilities Division designed radiation-hardened magnets that can operate properly after very high doses. This has resulted in fewer repairs, which in turn reduces the dose burden because staff is working less frequently on broken, activated equipment. Additionally, the Accelerator Division has improved beam monitoring systems and procedures that achieve better control of beams, which results in less activation of equipment.

C-AD Features To Reduce Dose And The Spread Of Radioactive Materials

- Soil is capped with a water-impermeable membrane to prevent soil activation from becoming a leachate that can reach groundwater.
- Multi-leg penetrations and labyrinths are used to minimize routine radiation levels.
- A re-entrant cavity and movable shield are used to minimize exposure to residual radiation in the Target Room from beam stop radioactivity.
- A sample translator or relay apparatus is used, when applicable, to minimize entrances to the Target Room.
- A sump and sump alarm are located in the beam line to capture cooling water should it leak.
- All drain piping in the facility is connected to the BNL Sanitary Sewage System.
- All cooling water systems have water make-up alarms.
- There are no outdoor tritiated water piping or cooling systems.
- An isolated closed cooling-water system was used to reduce the volume of tritiated water.
- The domestic water supply is equipped with back-flow preventers to isolate the Booster Applications Facility domestic water supply systems.
- Hoods and individual laboratory ventilation are used for radioactive tracer materials and hazardous materials in the Support Laboratories.
- Air and short-lived airborne radioactivity are re-circulated to allow for decay in the Booster Applications Facility beam line during operations.
- Air emissions from the Target Room are vented to the outside. Airflow direction is from the Support Laboratories into the Target Room and out the exhaust point.

- Dual, fail-safe interlocks are used on gate entrances.
- Interlocked access-key-trees are used to capture gate access keys.
- An iris reader or a similar bio-identification system is used to release an access key to a trained individual.
- Crash cords are mounted inside the target cave and beam line.
- Interlocking area radiation monitors with pre-set trip levels are located throughout the NSRL.
- Audible and visual warnings are issued before re-enabling the beam line and target cave to receive beam.
- The beam line and Target Room are fully enclosed to prevent access during operations.
- Fencing is used to limit access to other radiological areas.
- Shielding is thick enough to prevent exposure to primary beam.

Post-Construction Review Of Effectiveness Of Engineering Features

The following post-construction reviews are required by C-A OPM procedures:

- Activated soil caps are examined for cracks, tree or shrub root penetration and standing water annually, before each running period.
- Fault studies aimed at proving the effectiveness of shielding and the optimum placement of fixed radiation monitors are conducted before routine operations.

- The access control system is tested before operations with beam and annually thereafter.
- Fencing and posting is examined by the liaison engineer and liaison physicist before initial operations with beam, and before each running period thereafter.
- Groundwater monitoring results are examined annually by C-AD management.
- Collective-dose is reviewed by the ALARA Committee annually.